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Moisture-dependent Physical and Compression Properties of Bitter Melon (*Citrullus colocynthis lanatus*) Seeds

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ABSTRACT

Bitter melon seed (Egusi) is of medicinal value in addition to being a food source, biofuel and in cosmetics. Its dehulling has been a problem to its farmers and properties are moisture dependent. The aim of determination of these properties is to guide the design of processing equipment for planting, storing, dehulling and other post-harvest processing. In moisture range of 7.11-38.70% in dry basis, 1000 seed mass increased from 0.0949-0.1299 kg and surface area from 25.394-27.827 mm^2 while geometric and arithmetic mean diameters were 2.83-2.98 and 7.66-8.79 mm, respectively,. At moisture level of 7.11% in dry basis, average length, thickness and width of Egusi "bitter" melon seed were 13.199, 1.853 and 7.924 mm, respectively. Decrease was recorded for Sphericity (from 0.215-0.196) and Porosity (0.541-0.444%) while angle of repose increased from 23.66-33.63°. Bulk density rose from 414.006-456.339 kg m^{-3} while true density decreased from 901.515-821.668 kg m^{-3}. Coefficient of friction on aluminium (0.2736-0.3172) and PVC (0.2999-0.3782) plywood (0.3388-0.3598), metal (0.2767-0.3198), were obtained by relating the angle made to the height, as the seeds start to slide along an inclined plane made of each material. Seed hull breaking force on horizontal axis increased but a decrease was observed on vertical axis.

Key words: Bitter melon, seeds, compression properties, moisture content, angle of repose, coefficient of friction, sphericity

INTRODUCTION

Citrullus colocynthis lanatus var *lanatus* seed, commonly called "Egusi", is grown in most African countries and used as food source, medicinal, Engineering and cosmetics (Jeffrey, 1980). One of the cucurbit species is largely believed to have originated from western Kalahari region of Namibia and Botswana. Bitter "Egusi" melon seed is a member of family of Cucurbitaceae, having excellent genetic diversity, up to and including vegetative and reproductive characteristics. Researchers agree that *Citrullus lanatus* is classified into three sub-species; *lanatus*, *mucosospermus* Fursa and *vulgaris* Fursa (Makajuola, 1972). Determining the physical properties of seeds is essential for design of equipment and other facilities for planting, harvesting, handling, conveying, drying, aeration, storing and dehulling. This study aimed at investigating some physical and compression properties of bitter melon seeds.

Fig. 1: Pictorial view of bitter melon seed

This specie is grown and used especially as food source in most parts of West Africa. Some of the species are edible and grown in most parts of the world (Enoch *et al*., 2008). It is a vine plant which grows on the ground and covers large area when properly grown. The leaves are alternatively arranged, blue-gray and deeply lobed (Jeffrey, 1980; Enoch *et al*., 2008). The yellow-green fruit at maturity is about the size of edible watermelon but its flesh is white and the back is often shiny. It has bitter taste that makes it inedible to human being, thus the name "bitter" melon.

Roasted seeds of this melon can be eaten individually and used extensively for cooking purposes, either as a soup additive or as cooking oil source. Before processing to any use, the seeds are usually removed. Recently, it has been proved to be a fed-stock for bio-fuel (Gusmini *et al*., 2004; Makajuola, 1972; Solomon *et al*., 2010). It is a source of amino acids such as arginine, vitamins B_1, vitamins B_2, niacin, tryptophan and methionine and minerals such as zinc, iron, potassium, phosphorus, sulphur, manganese, calcium, lead, chloride and magnesium (Akobundu *et al*., 1982; Onyeike and Acheru, 2002). The seed contain over 50% oil and about 30% protein and other nutrients (Oyolu, 1977). Girgis and Said (1968) reported its content of unsaturated fatty and linoleic acids which suggests possible hypocholesterolemic effect. Figure 1 shows a picture of the seeds with shell.

Physical properties of seeds are determined by engineers to give information in developing mechanical devices that will be used from planting to post-harvest processes. The main objective of this study is to determine the physical and compression properties of the seeds, so as to guide the design and development of melon seeds dehulling machine.

MATERIALS AND METHODS

Citrullus colocynthis lanatus seeds were obtained from Nigeria for the study. The experiment was carried out in University Putra Malaysia between 3rd October, 2011 and 9th January, 2012. The sample seeds were cleaned manually to remove all foreign materials such immature or broken seeds and small chaffs from flesh of the melon fruit and sand particles. Initial moisture content was determined by hot air-oven at 105±3°C overnight, following the ASAE (1994) standard S.352.3 (Yalcin, 2007; Oyelande *et al*., 2005; Coskun *et al*., 2006; Coskuner and Karababa, 2007). The initial moisture content of the seed was 7.11% in dry basis. Readings were repeated in ten replicates to reduce error to the acceptable level for all measurements.

Calculated amount of distilled water was added to the samples to achieve desired moisture content (Eq. 1) (Coskuner and Karababa, 2007; Yalcin, 2007; Oyelande *et al*., 2005; Dursun *et al*., 2007; Solomon and Zewdu, 2009). The sample seeds were kept in refrigerator for 3 days at 5°C in a sealed plastic container to allow for proper moisture distribution. This rewetting technique was used by Enoch *et al*. (2008), Nimkar *et al*. (2005) and Sacilik *et al*. (2003). Before starting the experiment, only required quantity of seeds are removed and allowed to cool to room temperature for two hours:

$$Q = \frac{Wi\ (Mf\text{-}Mi)}{(100\text{-}Mf)} \tag{1}$$

All physical properties of the seed were assessed at moisture levels of 7.11, 14.65, 28.07 and 38.70% in dry basis with ten replications. Basic dimensions of the seed (length, width and thickness) were measured using digital micrometer screw gauge with accuracy of 0.001 mm (Mitutoyo Digital outside Micrometer, Series-193) as in study of Vilche *et al*. (2003), Aviara and Haque (2000).

An electronic digital balance with accuracy of 0.001 g (Mitutoyo Digital Scale, Mitutoyo America Corporation), was used to determine the 1000 seed mass, by sample size of 250 seeds randomly selected and weighted and multiplied by four (Sharma *et al*., 2011; Ozarslan, 2002; Vilche *et al*., 2003).

Average bulk density of the seed was obtained using standard test weight procedure by filling a 500 mL container with seed from a height of 150 mm at a constant rate and reweighting the content. The bulk density was calculated from the mass of seed and volume of the container, with no separate manual compaction of seeds (Oyelande *et al*., 2005; Sharma *et al*., 2011). Volume, weight and bulk density were evaluated from Eq. 2-4:

$$V_b = \pi r^2 h \tag{2}$$

$$W_s = W_{s+b}\text{-}W_b \tag{3}$$

$$\rho_b = W_s/V_b \tag{4}$$

Using distilled water displacement method, true density of seed was determined as ratio of mass used and volume of seed (Dutta *et al*., 1988; Omobuwajo *et al*., 2000; Sacilik *et al*., 2003; Ozarslan, 2002; Gupta and Das, 2000). A 250 mL beaker containing 100 mL of distilled water was used. Amount of water displaced was measured. Porosity was determined by equation five using values of bulk and true densities (Mohsenin, 1980; Jain and Bal, 1997):

$$\varepsilon = \left(\frac{1\text{-}\rho_b}{\rho_t}\right)\times 100 \tag{5}$$

Coefficient of static friction is the ratio of force required to start sliding a given sample over a particular surface to the normal force which is the weight of the object (Bahnasawy, 2007). Static coefficient of friction of the seed, μ was tested on four different material surfaces; aluminium, plywood, metal sheet and plastic (PVC). Tilting platforms of 330 mm by 200 mm were used. A two sided, open ended cylindrical shaped plastic material with dimensions 70 mm (base), 50 mm (height) was used. It was filled to brim with the seed and placed on the material surfaces and gently lifted, so that, only the seeds are in contact with surface. The platform was lifted gently with the cylinder containing the seeds resting on it, with a digital lift (Mitutoyo height measuring instrument) until the container begins to slide. Height at which the slide began was h and distance from the base of platform to the base of the lifting equipment was d, coefficient of friction μ and angle of tilt α was evaluated using Eq. 6 (Nimkar *et al.*, 2005; Singh and Goswami, 1996; Baryeh, 2001, 2002; Suther and Das, 1996):

$$\mu = \tan\alpha = h/d \tag{6}$$

Arithmetic mean diameter D_a, geometric mean diameter D_g and sphericity of seed were evaluated using basic dimensions. These were computed using Eq. 7-9 (Mohsenin, 1980; Bahnasawy, 2007; Karaj and Muller, 2010):

$$D_a = (L+W+T)/3 \tag{7}$$

$$D_g = (LWT)^{1/3} \tag{8}$$

$$\phi = (LWT)^{1/3}/L \tag{9}$$

Angle of Repose was determined by use of an open ended circular material (60 mm by 80 mm). The container was carefully raised until it is free of the seed. Cone shape was made by the seeds. Height of cone was measured. Angle of repose was calculated using Eq. 10 (Kalamullah and Gunasekar, 2002; Garnayak *et al.*, 2008; Karababa, 2006; Fraser *et al.*, 1978):

$$R_a = \tan^{-1}(2H/D) \tag{10}$$

Surface area of seed was determined from the geometric mean diameter (Eq. 11), (Sharma *et al.*, 2011; Garnayak *et al.*, 2008; Altuntas *et al.*, 2005; Tunde-Akintunde and Akintunde, 2004):

$$S = \pi D_g^2 \tag{11}$$

Egusi seed was subjected to compression on vertical and horizontal directions as shown in Fig. 2. An Instron Machine, (SATEK Series DX Model, 5565) was used to determine the force required to break the hull at different moisture levels. The seed was crushed between two metallic surfaces at a cross-head speed of 0.5 mm min^{-1}, until fracture of the hull was achieved for each of the ten replicates at four moisture content levels (Baumler *et al.*, 2006; Olaniyan and Oje, 2002; Teotia *et al.*, 1989; Akaaimo and Raji, 2006).

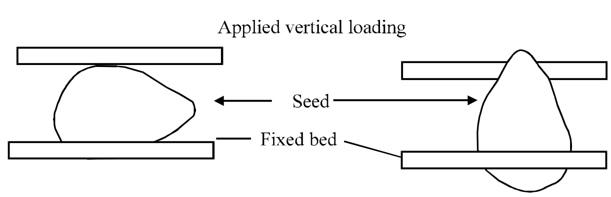

Fig. 2: Vertically and horizontally aligned seeds

RESULTS AND DISCUSSION

Dimensions: Figure 3 presents the variations of each parameter with moisture content. About 70% of the seed have a length between 13.0-13.57 mm; 70% have thickness between 1.62-1.99 mm and about 80% have between 7.75-7.99 mm as width. The mean dimensions of 1000 seeds measured at 7.11% dry basis moisture content were: length 13.199±0.464 mm, thickness 1.853±0.287 mm and width 7.924±0.143 mm (Singh and Goswami, 1996; Enoch *et al.*, 2008; Dursun *et al.*, 2007; Nimkar *et al.*, 2005). Length of seed increased from 13.2-15.3 mm, thickness from 1.85-2.56 mm while width of the seed rose from 7.92-8.59 mm within the moisture content range of 7.11-38.70%. These values were related to the moisture content by Eq. 12-14, respectively:

$$L = 12.7055+0.05844\ MC \quad (R^2 = 0.8998) \tag{12}$$

$$T = 1.6924+0.02176\ MC \quad (R^2 = 0.9929) \tag{13}$$

$$W = 7.7431+0.01996\ MC \quad (R^2 = 0.9257) \tag{14}$$

Surface area: Increased moisture content has increased the surface area from 25.39-27.83 mm^2. This is expected since the surface area is a function of geometric diameter (Fig. 4). Similar report was presented by Baumler *et al.* (2006) on safflower, Altuntas *et al.* (2005) on fenugreek seeds; Omobuwajo *et al.* (2000) on calabash nutmeg seeds. They were related by Eq. 15:

$$S_a = 24.7978+0.07212\ MC \quad (R^2 = 0.9355) \tag{15}$$

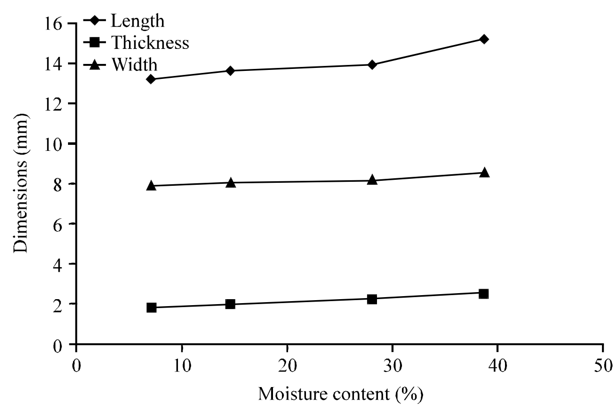

Fig. 3: Moisture variation with length, thickness and width of seed

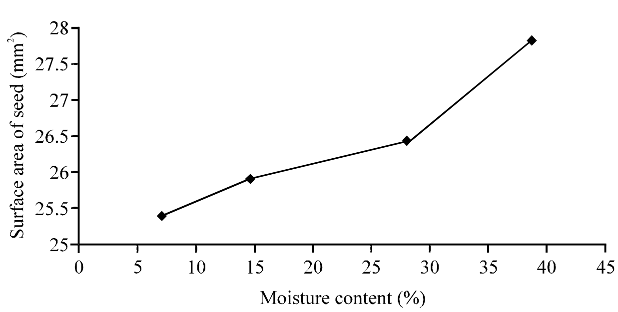

Fig. 4: Surface area variation with moisture

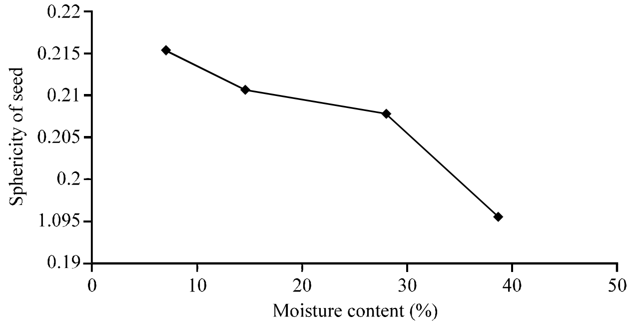

Fig. 5: Variation of sphericity with moisture

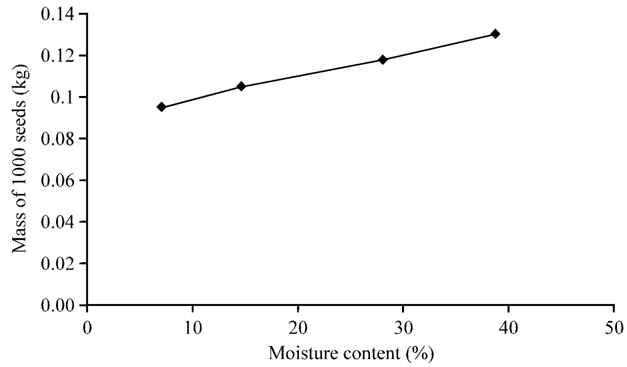

Fig. 6: Moisture content variation with 1000 seed mass

Sphericity: Sphericity of the seed decreases from 0.2154-0.1956 with increase of moisture content range. This is similar to findings of Dutta *et al.* (1988) and Oje and Ugbor (1991) on rapeseed, gram and oil bean, respectively. Figure 5 shows the relationship of moisture content with sphericity. The relationship is as in Eq. 16:

$$S = 0.2200+0.00057\ MC \qquad (R^2 = 0.8973) \tag{16}$$

1000 seed mass: Mass of 1000 seeds increased from 0.09491-0.12992 kg as shown in Fig. 6. Consequently, average of 10 replicates produces a standard deviation of the mass from 0.005073-0.001064. Coefficient of determination of 99.74% was recorded. An increase of 36.9% in 1000 seed mass was recorded within the working range of moisture. Similar trend was reported on *Prosopis africana* (Akaaimo and Raji, 2006), Jatropha seed (Garnayak *et al.*, 2008), quinoa seeds (Vilche *et al.*, 2003; Sacilik *et al.*, 2003) for hemp seed. Also, Karababa (2006) reported on popcorn kernel, with safflower seeds by Baumler *et al.* (2006). The relationship between them was as in Eq. 17:

$$M_{1000} = 0.08783+0.00109\ MC\ (R^2 = 0.9974) \tag{17}$$

Arithmetic and geometric diameters: These parameters were therefore directly related to basic dimensions and as such, increase in length, thickness and width of the seeds produces corresponding increase in the diameters. The arithmetic and geometric diameters were found to

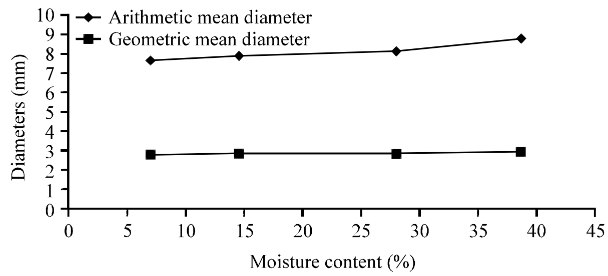

Fig. 7: Moisture vs. arithmetic and geometric mean diameters

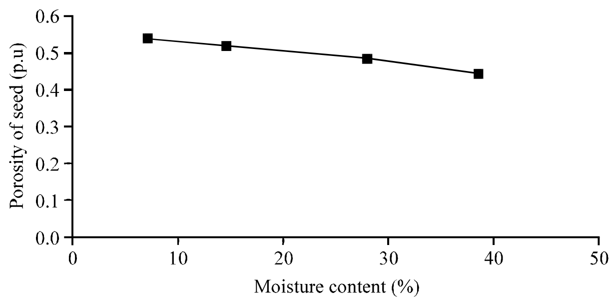

Fig. 8: Variation of porosity with moisture content

have increased with moisture content as similarly reported by Dutta *et al.* (1988) in gram seeds; Bahnasawy (2007) in garlic; Aviara and Haque (2000) in guna seeds; Sharma *et al.* (2011) in tung seeds (Fig. 7). Arithmetic and geometric mean diameters increased from 7.66-8.79 and 2.84-2.98 mm, respectively within the range of moisture.

Porosity: Porosity was observed to decrease with increase in the moisture content as shown in Fig. 8. This is a property that depends on the densities (bulk and true) and differs with seed. It is a value of the "empty" space in the seed. It is useful especially in seed storage and processing, as it guides in knowing the amount of seed that goes into the planter tube or dehuller. The experiment shows that it decreases from 0.541-0.445. Porosity relationship to moisture content is represented by Eq. 18:

$$P = 0.5645 - 0.003\ MC \qquad (R^2 = 0.9922) \tag{18}$$

Similar trend was reported by Suther and Das (1996) in karingda seeds; Visvanathan *et al.* (1996) in neem nut; Deshpande *et al.* (1993) in soybeans; Dursun *et al.* (2007) in sugar beet; Sacilik *et al.* (2003) in hemp seed. However, Garnayak *et al.* (2008) in jatropha, reported porosity increase.

True and bulk densities: True density decreased with the increase in moisture content as was similarly reported by Ozarslan (2002), Dutta *et al.* (1988), Sacilik *et al.* (2003), Omobuwajo *et al.* (2000), Gupta and Das (2000). At 7.11% the true density was 901.515 kg m^{-3} and decreases to 821.668 kg m^{-3} at 38.70% moisture level. The decreasing relationship is almost linear (Fig. 9). True density is related to moisture content by Eq. 19 and 20 for bulk density:

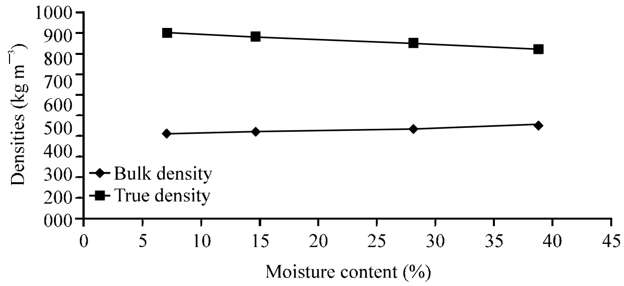

Fig. 9: Moisture content vs. true density and bulk density

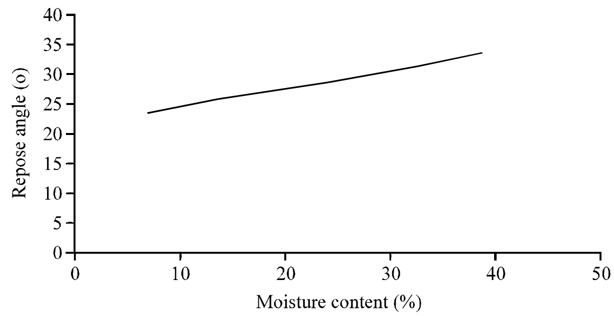

Fig. 10: Moisture content and repose angle

$$T_d = 921.3631\text{-}2.53976\ MC \quad (R^2 = 0.9973) \tag{19}$$

$$\rho_d = 404.3628+1.30542\ MC \quad (R^2 = 0.9917) \tag{20}$$

Increase in Bulk density from 414.006 kg m^{-3} at 7.11% to 456.339 kg m^{-3} at 38.70% moisture level was recorded. The pattern was similarly reported by Sharma *et al.* (2011), Oyelande *et al.* (2005), Kingsly *et al.* (2006) on dried pomegranate; Aydin and Ozean (2002) on terebinth.

Repose angle: Increase was recorded in angle of repose from 23.66-33.63° as moisture increases from 7.11-38.70%. Friction increases on the surface of the seeds, thereby making the seeds less able to flow on one another. Similar trend was reported by Garnayak *et al.* (2008), Kalamullah and Gunasekar (2002), Karababa (2006) and Fraser *et al.* (1978). This is shown in Fig. 10. Equation 21 relates the two variables:

$$R_a = 21.4970+0.30752\ MC \quad (R^2 = 0.9949) \tag{21}$$

Compression: The force required to crack the seed was determined on the vertical axis. It reduces with increasing moisture value and increases on the horizontal axis as shown in Fig. 11. The vertical force required to break the hull of the seed reduces from 7.47055-5.10684 N. However, force required to break the hull on horizontal axis increased from 8.41984-12.12963 N. Similar readings were reported by Baumler *et al.* (2006), Murthy and Bhattacharya (1998) and Gupta and Das (2000). These properties were defined by Eq. 22 and 23:

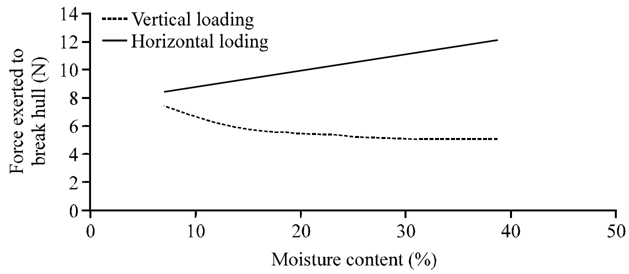

Fig. 11: Hardness of seed on the horizontal and vertical axes with moisture variation

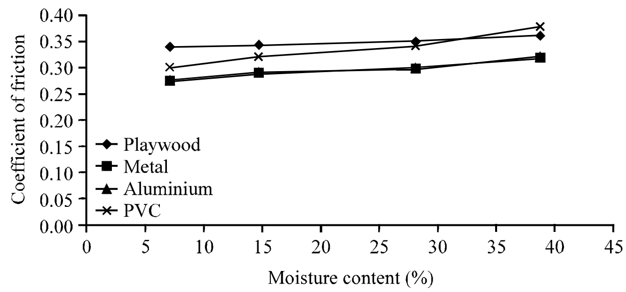

Fig. 12: Variation of moisture and frictions on different surfaces

$$H_v = 7.4458\text{-}0.0681\ MC \quad (R^2 = 0.79183) \tag{22}$$

$$H_h = 7.6741+0.1143\ MC \quad (R^2 = 0.9960) \tag{23}$$

Coefficient of friction: Four different surfaces were used in the experiment; plywood, plastic (PVC), metallic and aluminum foil surfaces (Fig. 12). On all the surfaces experimented on, the value of coefficient of friction increased with increasing moisture value; 0.3388-0.3598, 0.2767-0.3198, 0.2736-0.3172 and 0.2999-0.3782 for plywood, metal, aluminum and PVC surfaces, respectively. Coefficients of friction on different surfaces were related to the moisture content Eq. 24-27.

$$Cf_{plywood} = 0.3334+0.00063\ MC\ (R^2 = 0.9973) \tag{24}$$

$$Cf_{metal} = 0.2683+0.0012\ MC\ (R^2 = 0.9973) \tag{25}$$

$$Cf_{aluminium} = 0.2662+0.0013\ MC \quad (R^2 = 0.9973) \tag{26}$$

$$Cf_{PVC} = 0.2821+0.00236\ MC \quad (R^2 = 0.9973) \tag{27}$$

Similar trends were reported by Kingsly *et al.* (2006) in pomegranate; Amin *et al.* (2004) in lentil seeds; Teotia *et al.* (1989) in pumpkin seeds and Solomon and Zewdu (2009) in niger seeds.

CONCLUSION

Conclusions are drawn from the investigation on physical and compression properties of bitter melon seed for the moisture content range from 7.11-38.70%. Bulk density of the seed increased while true density decreased. Angle of repose rose from 23.66-33.63° within the range of moisture and thousand seed mass also increased from 0.094-0.130 Kg, similar to surface area. Both sphericity and porosity reduces within the range from 0.215-0.196 and 0.541-0.444, respectively and Harness of seed increases from 8.42-12.13 N on the horizontal axis, with decrease on the vertical axis. However, coefficient of friction on all the four tested surfaces also increased as the moisture content increased.

NOMENCLATURE

M_i	=	Initial moisture content (%)	ρ_b	=	Bulk density (Kg m^{-3})
M_f	=	Final moisture content (%)	h	=	Height of beaker (mm)
L	=	Length of sees (mm)	ϕ	=	Sphericity of seed
T	=	Thickness of seed (mm)	W_i	=	Initial weight of sample (kg)
W	=	Width of seed (mm)	D_g	=	Geometric mean diameter (mm)
Q	=	Mass of water added to seed (kg)	D_a	=	Arithmetic mean diameter (mm)
W_b	=	Weight of beaker (kg)	W_s	=	Weight of seed (Kg)
V_b	=	Volume of beaker (m^3)	W_{s+b}	=	Weight of seed+beaker (kg)
ρ_t	=	True density (Kg m^{-3})	ε	=	Porosity
h	=	Height of vertical stand for C of friction	d	=	Base distance of the sliding surface
D	=	Diameter of cone (mm)	H	=	Height of cone (mm)
μ	=	Coefficient of friction (p-plywood, m-metal, a-aluminium, PVC-pvc	S	=	Surface area (mm^2)
R_a	=	Repose angle (degrees)			

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